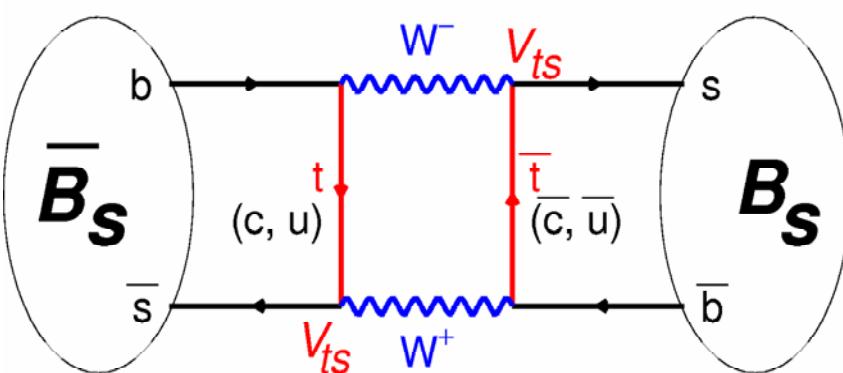
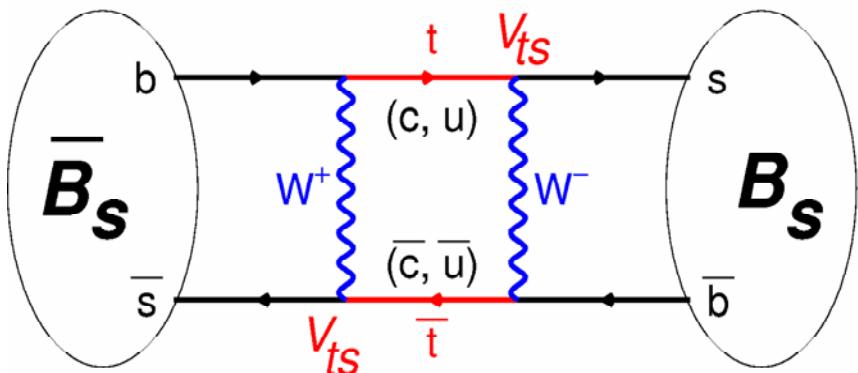




# $\Delta\Gamma(B_s^0)$ Measurements at DØ

Wendy Taylor  
York University  
for the DØ Collaboration

# $B_s^0 - \bar{B}_s^0$ Mixing



- 2 mass eigenstates are nearly-CP eigenstates
  - $|\mathbf{B}_{s,L}\rangle \approx \text{CP even}$
  - $|\mathbf{B}_{s,H}\rangle \approx \text{CP odd}$
- Have mass difference  $\Delta m_s > 0$

$$\Delta m_s = m_{s,H} - m_{s,L}$$

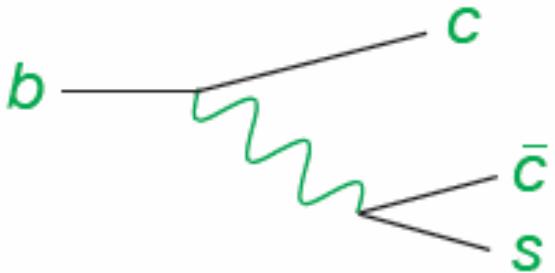
# Width Difference $\Delta\Gamma(B_s^0)$

- Two mass eigenstates have width (lifetime) difference  $\Delta\Gamma_s > 0$

$$\Delta\Gamma_s = \Gamma_{s,L} - \Gamma_{s,H} \quad \Delta\Gamma_s \ll \Delta m_s$$

- SM expectation:  $\Delta\Gamma_s = 0.10 \pm 0.03 \text{ ps}^{-1}$  Nierste 2006
- New physics tends to reduce measured  $\Delta\Gamma_s$

$$i \frac{d}{dt} \begin{pmatrix} |B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle \end{pmatrix} = \left( M - i \frac{\Gamma}{2} \right) \begin{pmatrix} |B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle \end{pmatrix}$$



- $M_{12}$  and  $\Gamma_{12}$  give rise to  $B_s^0 - \bar{B}_s^0$  mixing



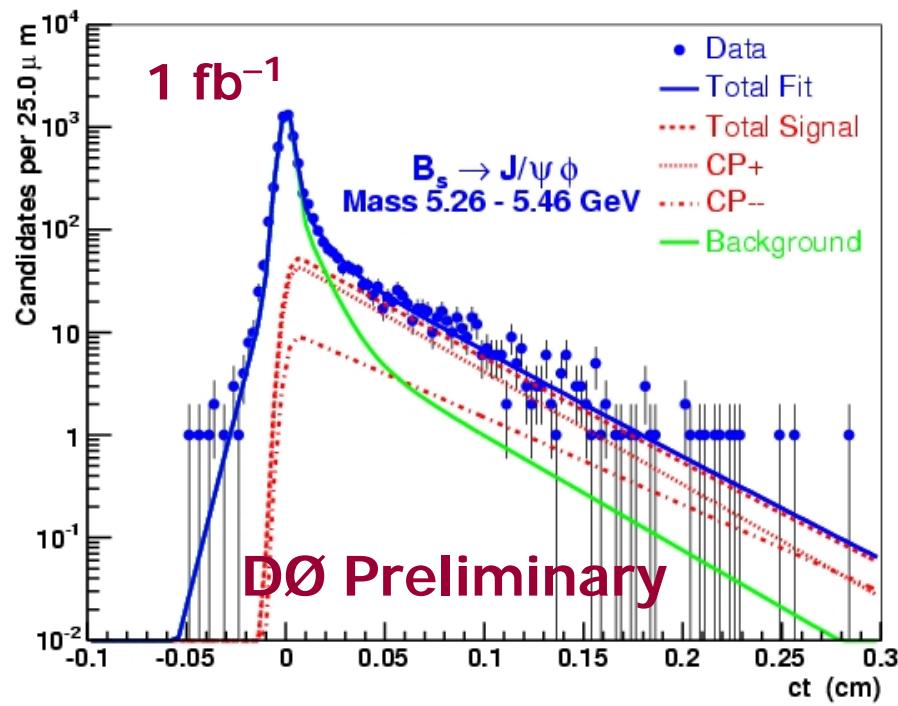
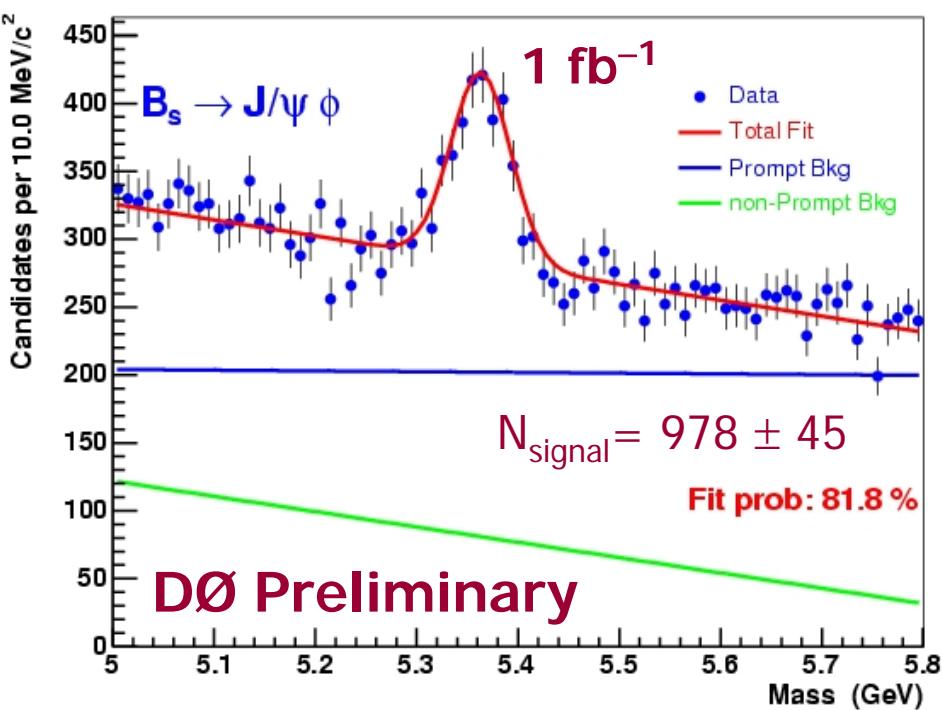
# Width Difference $\Delta\Gamma(B_s^0)$

- $B_s^0 \rightarrow J/\psi \phi$  is Pseudoscalar  $\Rightarrow$  Vector Vector decay
  - yields both CP-even and CP-odd final states
- Different angular distributions for  $|B_{s,L}\rangle, |B_{s,H}\rangle$ 
  - Can separate the CP components via a time-dependent angular analysis of decay products
- Decay products
$$J/\psi \rightarrow \mu^+ \mu^-, \phi \rightarrow K^+ K^-$$
  - Plot distributions of the “transversity” angles  $\theta, \phi, \Psi$

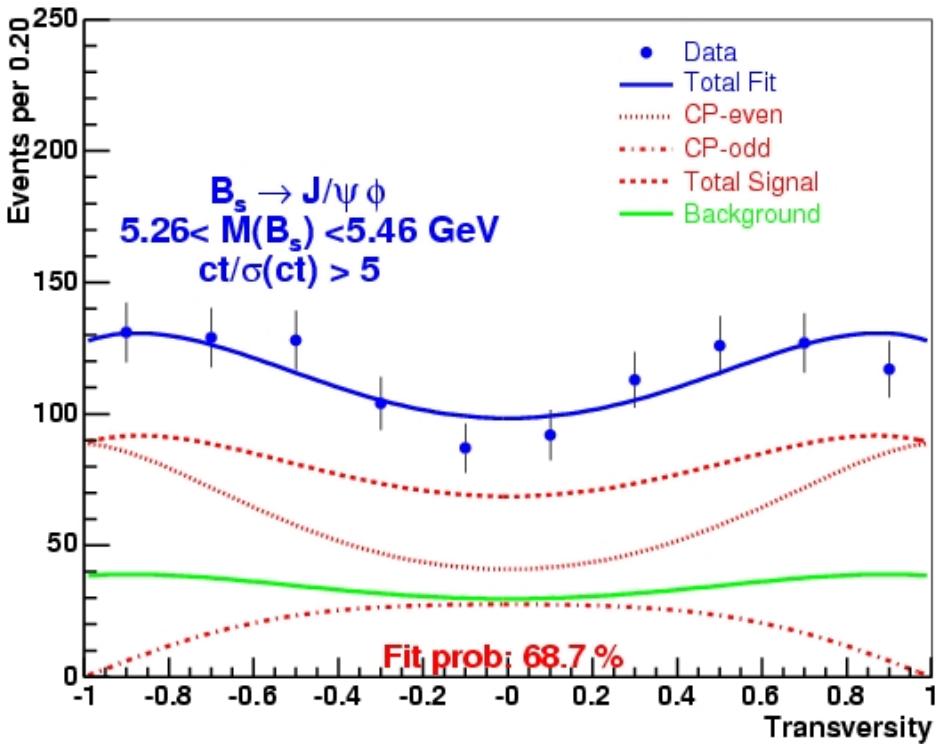
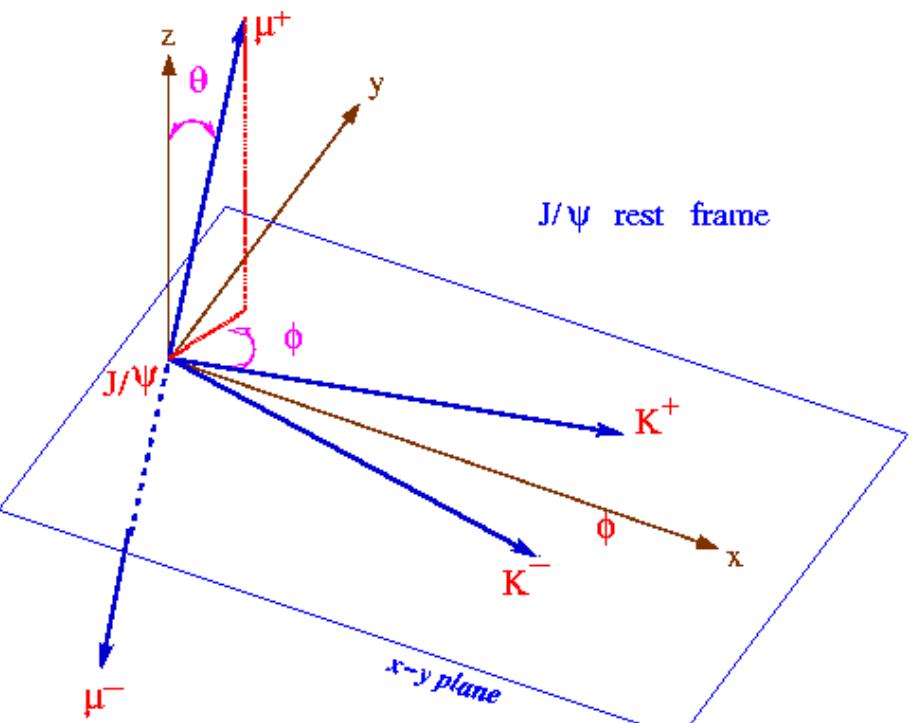
# $B_s^0 \rightarrow J/\psi \phi$ Mass and Lifetime

- Simultaneous fit to mass, proper decay length and 3 angles using an unbinned maximum log-likelihood method

$$\mathcal{L} = \prod_{i=1}^N [ f_{sig} F_{sig}^i + (1 - f_{sig}) F_{bck}^i ]$$



# Transversity Angle Distribution



## Transversity angle $\theta$



# Results of the Fit

- Assuming no CP violation in  $B_s^0 - \bar{B}_s^0$  mixing

$$\Delta\Gamma_s = 0.12 \pm 0.08(stat)^{+0.03}_{-0.04}(syst)\text{ps}^{-1}$$

$$\bar{\tau}(B_s^0) = \frac{1}{\bar{\Gamma}_s} = 1.52 \pm 0.08(stat)^{+0.01}_{-0.04}(syst)\text{ps}$$



# CP Violation in $B_s^0 - \bar{B}_s^0$ Mixing

$$i \frac{d}{dt} \begin{pmatrix} \left| B_s^0(t) \right\rangle \\ \left| \bar{B}_s^0(t) \right\rangle \end{pmatrix} = \left( M - i \frac{\Gamma}{2} \right) \begin{pmatrix} \left| B_s^0(t) \right\rangle \\ \left| \bar{B}_s^0(t) \right\rangle \end{pmatrix}$$

- Define  $\varphi_s$ , the CP-violating phase in  $B_s^0 - \bar{B}_s^0$  mixing

$$\frac{M_{12}}{\Gamma_{12}} = - \left| \frac{M_{12}}{\Gamma_{12}} \right| e^{i\varphi_s}$$

$$e^{i\varphi_s} = \frac{V_{ts} V_{tb}^*}{V_{ts}^* V_{tb}} \frac{V_{cs}^* V_{cb}}{V_{cs} V_{cb}}$$

$$\Delta\Gamma_s = \Gamma_{s,L} - \Gamma_{s,H} = 2|\Gamma_{12}| \cos \varphi_s$$

- A “large” measurement of  $\varphi_s \Rightarrow$  New Physics!



# Results of the Fit

- Allowing for CP violation in the fit, we obtain

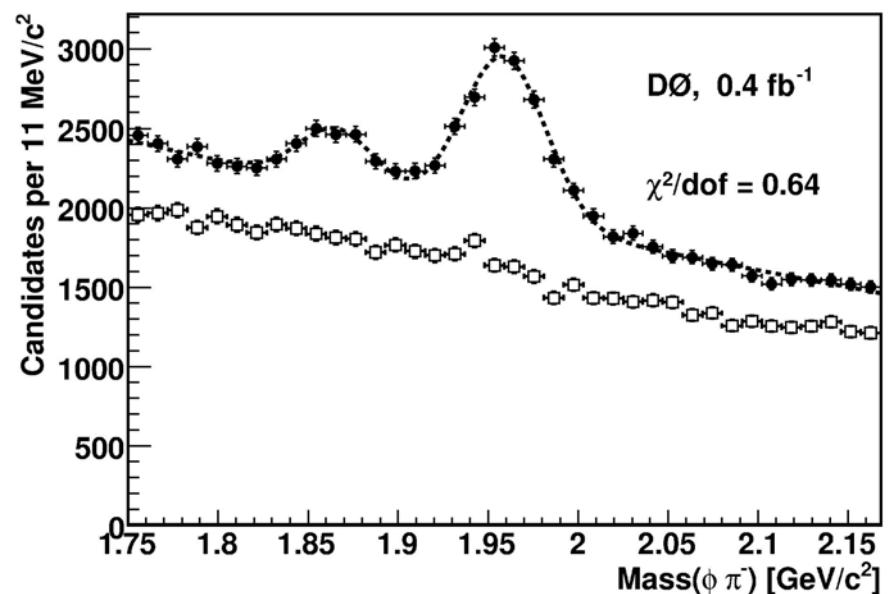
$$\varphi_s = -0.79 \pm 0.56(stat) \pm 0.01(syst) \text{rad}$$

$$\Delta\Gamma_s = 0.17 \pm 0.09(stat)^{+0.03}_{-0.04}(syst) \text{ps}^{-1}$$

$$\bar{\tau}(B_s^0) = \frac{1}{\bar{\Gamma}_s} = 1.49 \pm 0.08(stat)^{+0.01}_{-0.04}(syst) \text{ps}$$

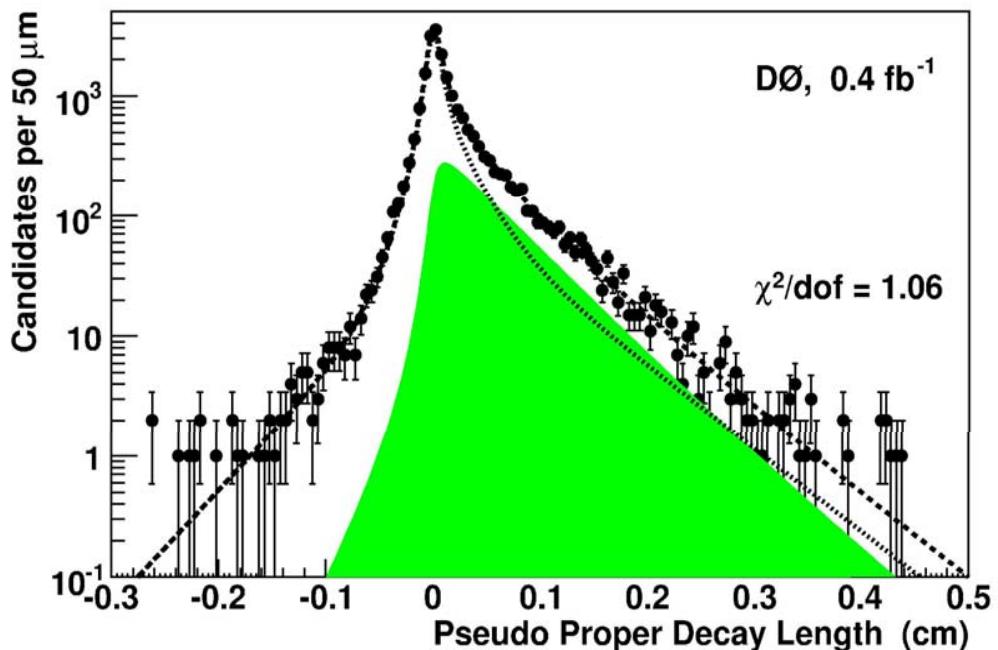
# Flavour-Specific $B_s^0$ Lifetime

- Reconstruct 5000  $B_s^0 \rightarrow D_s^- \mu^+ \nu X$  decays in  $400 \text{ pb}^{-1}$
- 50% CP-even, 50% CP-odd at time  $t=0$
- Fit lifetime to single exponential



$$\tau_{fs}(B_s^0) = \frac{1}{\bar{\Gamma}_s} \frac{1 + (\Delta\Gamma_s / 2\bar{\Gamma}_s)^2}{1 - (\Delta\Gamma_s / 2\bar{\Gamma}_s)^2}$$

# Flavour-Specific $B_s^0$ Lifetime



Submitted  
to  
PRL

- Most precise measurement to date:

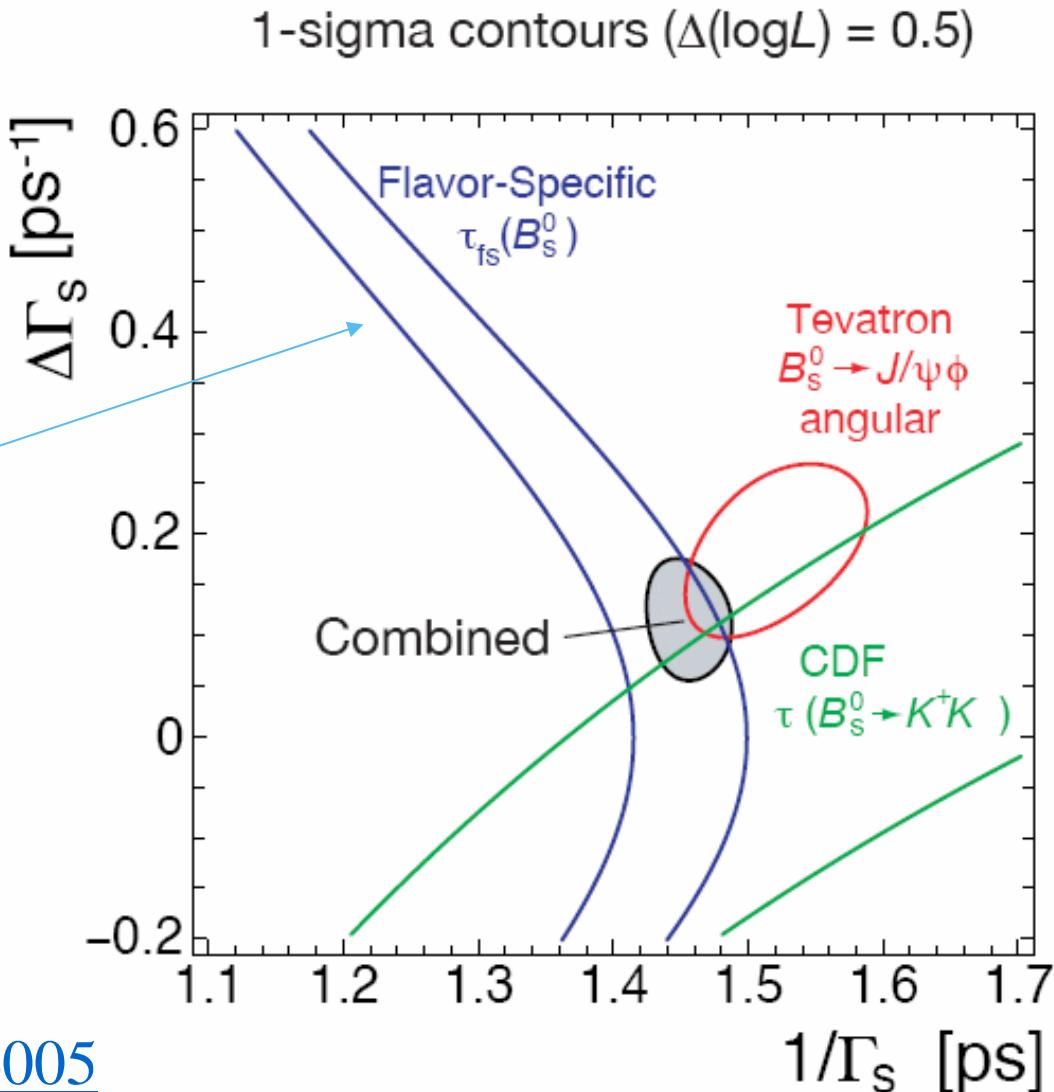
$$\tau_{fs}(B_s^0) = 1.398 \pm 0.044(\text{stat})^{+0.028}_{-0.025}(\text{syst})\text{ps}$$

- PDG world average:  $\tau_{fs}(B_s^0) = 1.442 \pm 0.066 \text{ ps}$

# Flavour-Specific $B_s^0$ Lifetime

$$\tau_{fs} = \frac{1}{\bar{\Gamma}_s} \frac{1 + (\Delta\Gamma_s / 2\bar{\Gamma}_s)^2}{1 - (\Delta\Gamma_s / 2\bar{\Gamma}_s)^2}$$

- Precise measurement of flavour-specific decays further constrains  $\Delta\Gamma_s$  and  $\bar{\Gamma}_s$



R. Van Kooten: [hep-ex/0606005](https://arxiv.org/abs/hep-ex/0606005)



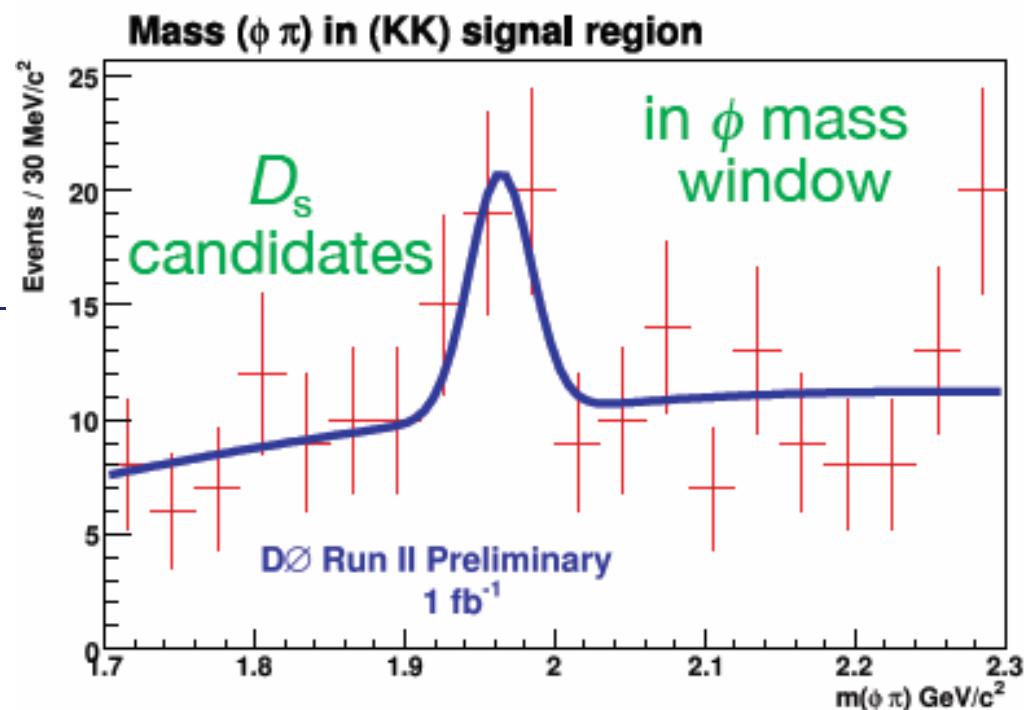
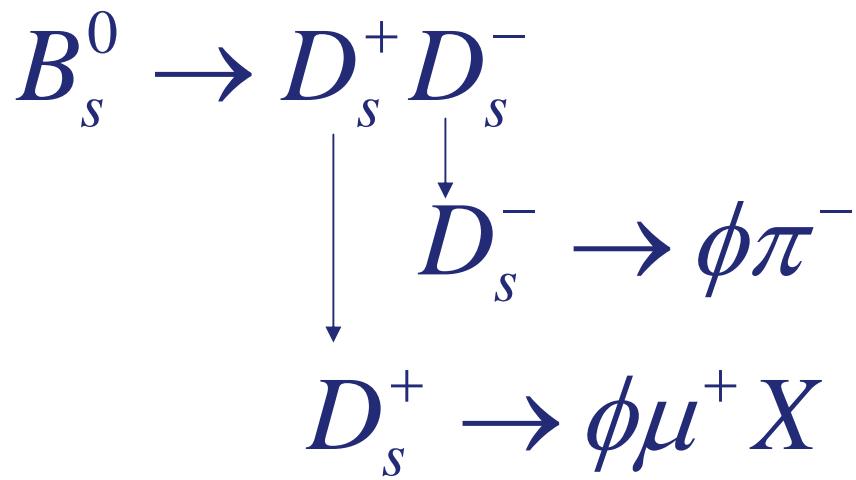
$Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-})$  and  $\Delta\Gamma(B_s^0)$

- $B_s^0 \rightarrow D_s^+ D_s^-$  is pure CP even
- Under various theoretical assumptions, inclusive  $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$  is also CP even to  $\sim 5\%$ , so

$$\frac{\Delta\Gamma_s}{\bar{\Gamma}_s} \approx \frac{2Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-})}{1 - Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-})/2}$$

$Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-})$  and  $\Delta\Gamma(B_s^0)$

- Have 15K  $\mu D_s, D_s \rightarrow \phi\pi$  candidates
- Look for additional  $\phi$  meson near  $\mu D_s$  candidate
- $19.3 \pm 7.8$   $\mu\phi D_s$  candidates found





$Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-})$  and  $\Delta\Gamma(B_s^0)$

- Measure ratio:

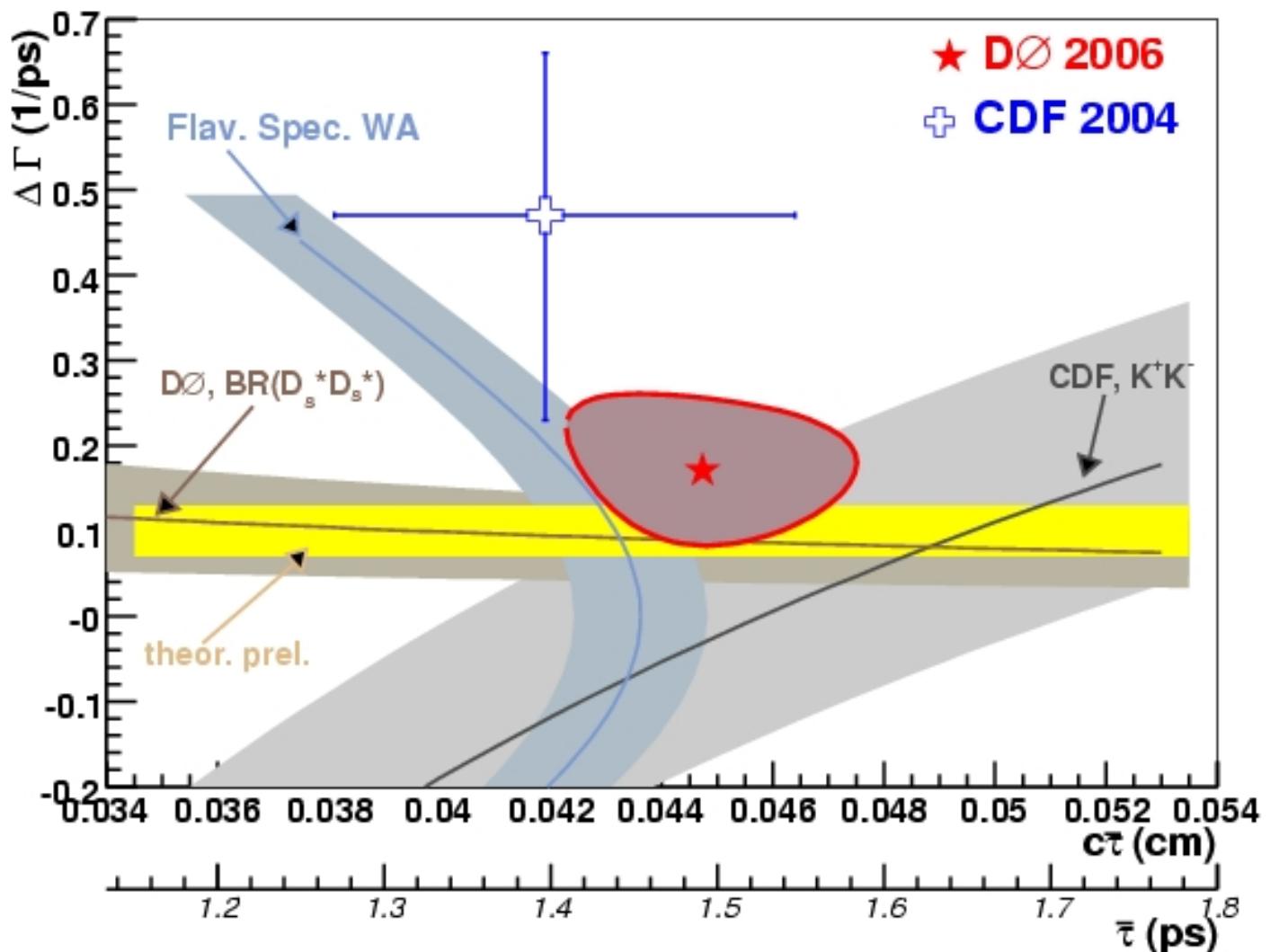
$$R = \frac{Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}) \cdot Br(D_s \rightarrow \phi \mu \nu)}{Br(B_s^0 \rightarrow \mu \nu D_s^{(*)-})}$$

- Many systematic uncertainties cancel in the ratio
- Use average of new BaBar meas't of  $Br(D_s^- \rightarrow \phi \pi^-)$  and PDG 2004 value
- Results:

$$Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}) = 0.071 \pm 0.032(stat)_{-0.025}^{+0.029}(syst)$$

$$\frac{\Delta\Gamma_s}{\bar{\Gamma}_s} = 0.142 \pm 0.064(stat)_{-0.050}^{+0.058}(syst)$$

# Latest Constraints on $\Delta\Gamma(B_s^0)$





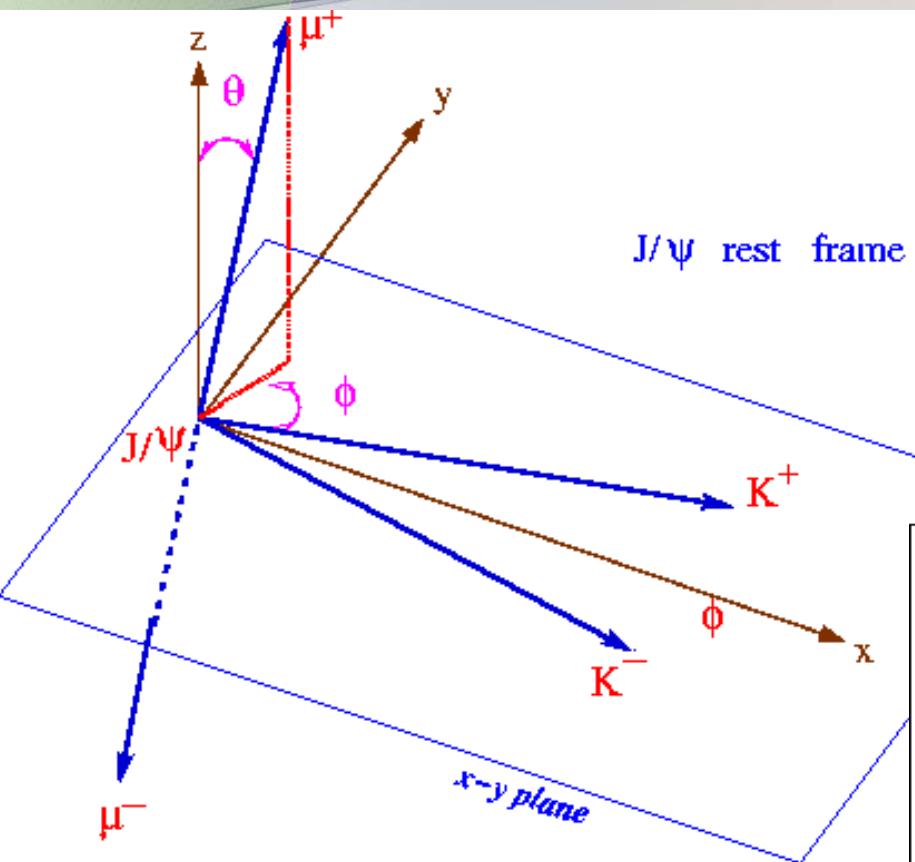
# Summary

- DØ has attacked  $\Delta\Gamma_s$  from several angles
- Results all consistent with SM expectations
- Stay tuned for more precise  $\Delta\Gamma_s$  results from DØ!



# Backup Slides

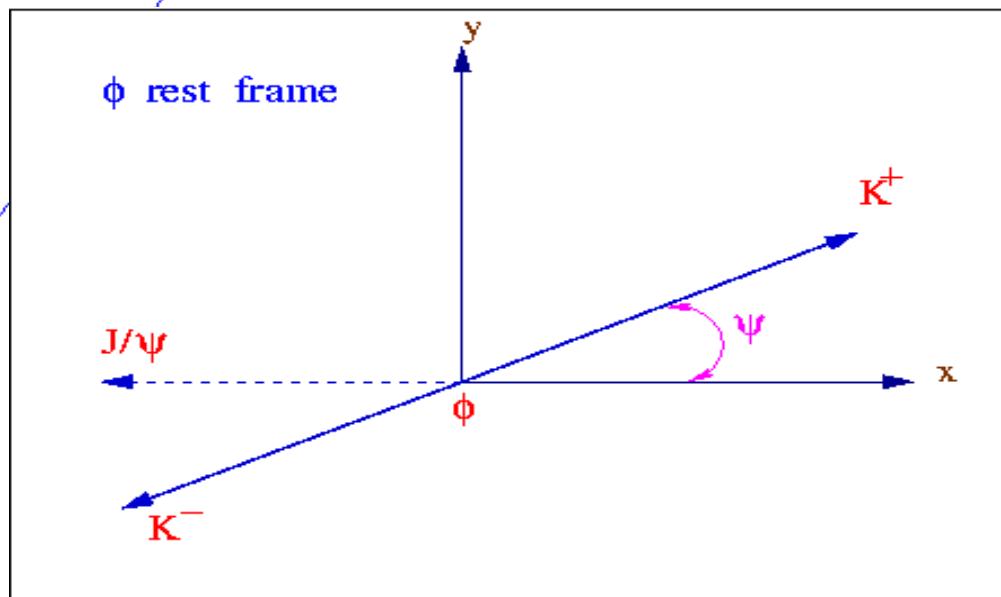
# Transversity Angles in $B_s^0 \rightarrow J/\psi \phi$



$J/\psi$  rest frame

$x-y$  plane

- Angles  $\theta$ ,  $\phi$ ,  $\psi$



$\phi$  rest frame

# Angular Distributions

